BERKELEY LAB RESEARCH HIGHLIGHT
MATERIALS SCIENCES DIVISION 00-9

Novel Nanosized Electronic Devices Fabricated

Carbon Nanotubes Used as Components of Transistors and Junctions

A research team led by Alex Zettl and Paul McEuen has succeeded in making novel nanosized electronic devices using carbon nanotubes. This work represents a significant step towards making functional electronics on the nanometer scale.

Single-walled carbon nanotubes (SWNTs), tiny wires of pure carbon only 1.4 nm in diameter, have attracted much attention as possible building blocks for molecular electronic devices. Previous LBNL work has shown that depending on the chirality, or twist, in the graphite lattice as it rolls to form the SWNT, nanotubes can be either metallic or semiconducting. More recently, the team demonstrated that individual metallic SWNTs can act as highly efficient conductors of electrons between metal contacts several microns apart. As reported in *Phys Rev. B* and in *Science*, the Zettl and McEuen groups have made two important breakthroughs in making a truly molecular scale electronics technology from SWNTs, namely the demonstration of transistor function and the connection of individual nanotubes with each other to make devices.

The LBNL team deposited nanotubes on a silicon wafer coated with an insulating oxide and labeled with fiduciary marks. Atomic force microscopy was used to locate the nanotubes and electron-beam lithography techniques were used to “write” metallic “source” and “drain” contacts to both ends of the tubes. The conducting plane beneath the oxide layer served as the third,“gate” electrode. With “as-grown” nanotubes, the source-drain conductance as a function of the gate voltage indicated p-type transistor function, in agreement with previous experiments. To convert the device to n-type, it was placed in a specially constructed furnace where a controlled amount of potassium vapor was deposited onto the nanotube. Electrons from the potassium were transferred to the nanotube, effectively doping it n-type. At certain levels of potassium exposure, the conductance plot became almost a “mirror image” of that of the p-doped device (see figure), exactly the behavior of an n-type field effect transistor.

In the next experiment, the team constructed more complicated devices consisting of two SWNTs forming a cross, with four electrical contacts, one at each end of each nanotube. This geometry allowed measurement of the electrical properties of each SWNT individually and also the electrical properties of the junction. Junctions between metal-metal, semiconducting-semiconducting and metal-semiconducting nanotubes were studied. Since the two nanotube “wires” in a junction are coupled only by weak van der Waals interactions, it was surprising that the metal-metal and semiconductor-semiconductor junctions have a very low resistance, approximately 200 kΩ, and can reliably pass currents of hundreds of nanoamps. Given the tiny area of the junction, this corresponds to enormous current densities on the order of 10^7 amps/cm^2. On the other hand, metal-semiconductor junctions showed quite different behavior. At low applied voltage bias, they had a much higher resistance (ca. 30 MΩ), but when the voltage was turned up, the resistance dropped, but only for current flow in one direction. This diode-like behavior, while characteristic of junctions between macroscopic metals and semiconductors (“Schottky barriers”), had never before been observed at such a small scale.

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